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Technical Note 283

NUCLEAR AND RADIATION STANDARDS OF IMPORTANCE TO THE NATIONAL ATOMIC ENERGY PROGRAM

H. W. KOCH, H. J. DONNERT, W. W. HAVENS, JR.,
G. L. ROGOSA, AND L. ROSEN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Institute for Basic Standards
National Bureau of Standards
Washington, D.C.

This report was compiled by the
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Nuclear and Radiation Standards of Importance to the National Atomic Energy Program

H. W. Koch
H. J. Donnert
W. W. Havens, Jr.
G. L. Rogosa
L. Rosen

A systematic approach to physical measurements in nuclear physics requires the establishment, availability, and use of standards. The standards of measurement may consist of standard cross sections, foils, counters, and evaluated nuclear data. Because of the fundamental importance of measurement standards, the Nuclear Cross Section Advisory Group has examined the definitions, requirements, characteristics, and availability of nuclear and radiation standards of importance to the national atomic energy program.

A. Introduction

A systematic approach to physical measurements in nuclear physics requires the establishment, availability, and use of standards. The standards of measurement may consist of standard cross sections, foils, counters, and evaluated nuclear data. Because of the fundamental importance of measurement standards, the Nuclear Cross Section Advisory Group has examined the definitions, requirements, characteristics, and availability of nuclear and radiation standards of importance to the national atomic energy program. This report presents the results of the examination and a statement of future needs. Although most of the research, development, and calibration services on the relevant standards are available at the National Bureau of Standards, the study covered the characteristics of all national standards work in the nuclear and radiation fields in the United States. The general availability of laboratory standards, calibrations, and services is not covered here.

B. Explanation of Terms

The more important terms as used in this report are defined and explained as follows:

1. Standard - A standard of measurement is the physical representation in a characteristic, object, or device of the unit of a physical quantity.

   (a) Unit - A unit is a particular sample of a physical quantity of such magnitude that it is assigned to measure "1". Units are either prototype or derived units. A prototype unit is one of the units for the five physical quantities upon which are based the measurement system. The five quantities are length, mass, time, temperature, and luminous intensity. The derived units are combinations of the prototype units, such as the unit for energy flux density, ergs per centimeter square per second.

   (b) Classification of Standards - Standards can be classified into a two-dimensional array according to categories and orders. The categories indicate the nature and use of the standards and the orders indicate the "authority" of the standards of each kind. The identification of a given characteristic, material, object, or device in a given category does not specify the quality, reliability, or authority of the standard. This specification is accomplished by the orders. Examples of categories are atomic or nuclear characteristics, standard instruments, or standard materials. Examples of the order of standards are national-prototype, national-reference, national-working, inter-laboratory-reference, laboratory-reference, and laboratory-working standards.

2. Radiation - Radiation includes charged particles (electrons, protons, alpha-particles, etc.) having sufficient kinetic energy to produce direct ionization by collision. Radiation also includes uncharged particles or photons which can liberate directly ionizing particles or can initiate a nuclear transformation. However, it does not include sound or radio waves, or visible, infrared, or ultraviolet light.

3. Radiation Standard - A radiation standard is the physical representation in a characteristic, object, or device of the unit of a fundamental radiation and non-nuclear quantity. Radiation standards are usually derived standards that can be expressed in terms of the five prototype standards for the quantities of length, mass, time, temperature, and luminous intensity. Examples of radiation standards are free-air ionization chambers for the measurement of x-ray exposure in roentgens and x-ray attenuation coefficients. The category of radiation standards does not include nuclear standards.

4. Nuclear Standard - A nuclear standard is the physical representation in a characteristic, object, or device of the unit of a fundamental nuclear quantity. Nuclear standards are usually derived standards that can be expressed in terms of the five prototype standards for the quantities of length, mass, time, temperature, and luminous intensity. Nuclear standards may represent a specifically designated unit for a nuclear energy level, transition probability, reaction cross section, Q value, threshold, mass, charge, magnetic moment, nuclear shape, or other nuclear quantity. Examples of nuclear standards are:

(a) (n,α) reaction cross section in centimeters squared for boron 10 at a neutron velocity of 2200 meters/cm^2.

(b) Neutron emission rate of a specific beryllium photoneutron source.

(c) Photoneutron threshold of beryllium 9 at 1.6665 MeV and of deuterium at 2.2261 MeV.

(d) Electric quadrupole moments in centimeters squared of carbon, aluminum, tantalum, and gold.

(e) Uranium isotopic mass standards.

(f) Standard foils of indium, gold, rhodium, etc. for neutron activation measurements.

C. Nuclear and Radiation Standards

The activities included in this survey of standards are neutron physics, radioactivity, x-ray and gamma-ray sources, isotopic mass standards, and data compilation and evaluation. The characteristics, availability, and statement of future needs are provided under the categories (sources, foils, detectors, chambers, cross sections, etc.) in each activity.

1. Neutron Physics

(a) Neutron Sources - The National Bureau of Standards possesses two radium-beryllium photoneutron sources of neutron emission rate about 10^6 neutrons/sec which serve as the national-standard and the national reference standard source. The national standard source has been absolutely calibrated three times at NBS, and is now known to an uncertainty of about 1 percent [1-4]. This source has been compared directly or indirectly with all of the national standard sources in the world, usually by the method of activation of a manganous sulfate bath, the agreement with the international mean value being better than 1 percent. Intercomparisons of these sources with other national standard sources are shown in Table 1 [5-11].

In addition, five plutonium 239-beryllium neutron sources are used as working standards. An americium 241-beryllium neutron source is on hand and is being studied as a possible future standard source. This source is of the sintered type to insure maximum stability with time. Curium 244 and californium 252 have been promised to NBS by the AEC for testing as possible spontaneous fission standard neutron sources. The sources, obviously, cannot play a significant role as standard neutron sources until the radioactive isotopes are available in reasonable quantities.

Sources are calibrated for the public by comparison with the national-standard source by activation of a manganous sulfate bath, except when the source strength of the submitted source is too small, in which case a calibration is made based on thermal neutron flux density measurements in a standard graphite pile [12]. (See Table 2a.) The errors quoted for the calibrations are 2.5 percent to 5 percent depending chiefly on the strength of the source. NBS has calibrated RA-Be(α,n), Pu-Be(α,n), RaDEF-Be(α,n), Sb-Be(γ,n), Po-Be(α,n), and Am^{241}-Be(α,n) sources with most of the work on the Pu-Be sources.

(b) Standard Thermal Neutron Flux Density - The National Bureau of Standards maintains a neutron moderation geometry with radioactive neutron sources which produce a thermal neutron flux density of about 4,000 neutrons/cm^2-sec. This facility is used by activation of foils, usually gold, but others such as indium and manganese may be used for special purposes. Up to 4 foils of size 2X3.4 cm may be calibrated at one time. Special arrangements for larger foils and other kinds of detectors are possible. Since the standard flux is located in an air cavity, the flux depression for gold foils of thickness less than 3 mils is negligible. Upon special requests other detectors such as thermal neutron pocket dosimeters may be calibrated [12]. (See Table 2b,c.) This standard thermal neutron flux density has been absolutely calibrated by two independent methods and compared with several laboratories. The uncertainty in the absolute calibration of this flux density is about 1.5 percent. An international comparison also shows agreement of about 1.5 percent.

(c) Standard Neutron Cross Section Materials -

(1) Boron Isotopic Standards. A stock of standard boric acid (H_3BO_3) is being distributed by NBS which was originally prepared for the U.S. Argonne National Laboratory and has been analyzed chemically and isotopically at Argonne [13]. (See Table 2.) The boron 10 content of this lot (called Argonne II) has been found at Central Bureau of Nuclear

Measurements, Geel, Belgium, to be 19.8 atomic percent and to be identical in isotopic composition to within ±0.02 atomic percent to the stock being distributed by them.

(2) Uranium and Plutonium Isotopic Standards. Sixteen uranium isotopic standards are available from NBS [12]. (See Table 2.) They represent the following nominal weight percent uranium 235: 0.5, 1, 1.5, 2, 3, 5, 10, 15, 20, 35, 50, 75, 80, 85, 90, and 93. Each isotopic standard is issued in a unit containing a quantity of uranium oxide (U_3O_8) equivalent to 1 g of uranium.

The plutonium isotopic standard is in the chemical form of plutonium sulfate hydrate. The weight percent of the plutonium isotopes in this standard are 91.329 (Pu-239), 7.9_{37}(Pu-240), 0.7_{00}(Pu-241), and 0.03_{34}(Pu-242). The issue unit contains a quantity of plutonium sulfate hydrate equivalent to 0.25 g of plutonium. A plutonium metal standard is also available that is certified to have a plutonium content of 99.97 percent by weight. The issue unit is 0.5 g.

(3) Laboratory neutron standards of boron glass for neutron cross sections measurements are available from the Corning Glass Works. Prepared in a special melt for this purpose, the boron glass standards are available in the form of 10-inch discs, 1/4 to 3/8 inches thick. Thinner and smaller samples can be cut and ground to the user's specifications. While minimum thickness is dependent on overall size, 2X2 inch samples have been prepared as thin a 0.5 mm. The glass contains approximately 13 percent B_2O_3. Other constituents are materials with low molecular weights and low neutron capture cross sections. Further information can be obtained from the Business Manager, Research and Development Laboratory, Corning Glass Works, Corning, New York. Neutron cross section measurements made with this glass are reported by Gould, et al [14].

(4) Standard Nuclear Foils. A program for the production of standard nuclear foils has been set up at Oak Ridge National Laboratory [15]. The ORNL program includes both the manufacture of foils and their measurement and calibration. These foils may be obtained by writing to E. Kobisk, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

(d) Neutron Detectors - The precision long counter of DePangher has been adopted by many laboratories in the United States and abroad, and recommended by the International Commission on Radiological Units and Measurements [16] as a standard neutron detection instrument. This counter has been shown to be very

reproducible in time and is recommended for consideration by laboratories needing such a fast neutron detector. Design drawings may be obtained by writing to W. C. Roesch, Hanford Laboratories, Richland, Washington.

(e) Neutron Cross Sections - The following neutron cross sections are of widely recognized importance as standards for comparison of measurements:

(1) H(n,n)H. This is the most basic cross section for neutron measurents above about 100 keV. Better angular distributions are required above about 15 MeV for highest accuracy in neutron flux density measurements.

(2) $He^3(n,p)$, $Li^6(n,\alpha)$ and $B^{10}(n,\alpha)$. The cross sections of these reactions should be measured with the highest possible accuracy above about 1 keV. All of these are already effectively standard cross sections for the < 1 keV neutron energy region because of their 1/v dependence. However, in the region between 1 and 100 keV these cross sections begin to deviate from 1/v and their energy dependence must be accurately determined. Furthermore, the $B^{10}(n,\alpha)$ cross section is often used as a standard by measurement of the 0.478 MeV gamma ray from an excited state of Li^7 and the branching ratio for the production of this gamma ray needs to be precisely measured.

The great importance of improved measurements of these three reaction cross sections is due to large discrepancies (as great as a factor of two in one instance) existing between cross sections measured by methods which individually should be good to 5 or 10 percent. Cross sections in the 1 to 100 keV energy range are needed for fast reactor design which should be good to 1 or 2 percent for reactions such as $U^{235}(n,f)$ and $U^{238}(n,\gamma)$.

(3) U^{235} and U^{238} Fission. Above about 1 keV for U^{235} and about 1 MeV for U^{238} these cross sections are extremely useful as working standards. For U^{235}, the region from 1 keV to 200 keV is the least well-known.

(4) Activation Cross Sections. There are many of these cross sections, some being useful as resonance detectors in the keV region, others as threshold detectors for fast neutron measurements. Some of the most useful are $Au^{197}(n,\gamma)$, $In^{115}(n,\gamma)$, $Rh^{103}(n,\gamma)$, $Mn^{55}(n,\gamma)$, $Co^{59}(n,\gamma)$, $In^{115}(n,n')$, $Np^{237}(n,f)$, $S^{32}(n,p)$, $P^{31}(n,p)$, $Cu^{63}(n,2n)$, and $C^{12}(n,2n)$.

2. Radioactivity - The National Bureau of Standards provides alpha, beta, and gamma-ray emitting artificially-produced radionuclides of known activity in the micro-curie range [12]. (See Table 3.) Radium standards are available in the range of 10^{-7} to 20 μg/ml. For most of the calibrated radionuclides now available, it appears that an accuracy of the order of 1 or 2 percent is obtainable as is indicated by comparison measurements of the same source at different national laboratories [17-28]. For some radioactivity standards, accuracies in the range from 0.1 to 1 percent are obtainable. Examples of the radioactivity standards that were made available during the last two years are solution standards of hydrogen 3-labeled water and toluene, chlorine 36, calcium 45, strontium 89, iodine 125, cerium 141, and mercury 203, and gamma-ray point-source standards of cesium-barium 137 and cerium 139 which are additions to the group of NBS gamma-ray point-source standards. These gamma-ray point-source standards have been comprised of some eight or nine different radionuclides emitting gamma rays ranging in energy from 0.166 to 1.85 MeV, but because of half-life not all are necessarily available at the same time [17].

   In addition to supplying radioactivity standards, radioactive sources can be supplied to NBS for calibration. The complete range of the Bureau's radioactivity standards and testing facilities is given in the price list shown in Table 3.

   In addition, the Bureau engages in a number of national and international comparisons of radioactivity measurements both in the range of its normal radioactivity standards and also in the low-level range, the latter including the American Society for Testing Materials, U.S. Public Health Service, and U. N. International Atomic Energy Agency intercomparisons of iodine 131, strontium 89, strontium-yttrium 90, cerium 141, and radium 226, in such media as water, evaporated milk, spinach, and rice flour.

   The normal (i.e., microcurie) range intercomparisons are carried out in connection with the program of the Bureau International des Poids et Mesures and have comprised some two to four intercomparisons a year for the last three or four years. They have included most of the world's radioactivity standardizing laboratories. The National Bureau of Standards also supplies radioactivity standards to practically every part of the Western World and a number of prominent laboratories base their own standards upon the Bureau's.

3. X- and Gamma-ray Sources - The National Bureau of Standards calibrates x and gamma-ray exposure measuring instruments in roentgens (R), radium sources (0.5 to 100 mg) in equivalent radium content, and cobalt 60 sources (15 to 200 mRh^{-1} at one meter) in exposure rate at one meter. The calibration services available from the National Bureau of Standards are described in Table 4. These calibrations are performed by a substitution method with the

national standards. For x rays of 250 kV or less, the national exposure standards are free-air chambers. NBS Handbook 64 gives the design criteria for such instruments [29]. The International Commission on Radiological Units and Measurements (ICRU) indicates [30] that the maximum uncertainty of such a device when used to measure moderately filtered x rays generated by potentials of 60 to 300 kV is about 1 percent. Recent estimates (to be published) indicate that the maximum uncertainty is about 1.3 percent at 10 kV [31]. Several direct comparisons of U.S. and other national free-air chambers have been performed with 60-250 kV x rays since 1950 [32-36]. These are listed in Table 5 together with the maximum differences obtained at any quality.

The U.S. standards for exposure measurement of cobalt 60 and cesium 137 gamma rays are cavity ionization chambers. It is estimated that the accuracy obtained with such instruments is within 2 percent but experiments are underway to reduce this uncertainty [37].

To reduce major disruption and transport difficulties associated with taking a national standard to the standards laboratory of another country, three terminal transfer instruments have been developed (1960) [33]. Such instruments were used to compare national standards of the Federal Republic of Germany, France, U.K., and U.S.A. [34]. Results obtained by this indirect method agreed to within 0.5 percent with that obtained earlier for French and U.K. standards. Together with Dr. F. R. Shonka (St. Procopius College, Lisle, Illinois), a thin-walled chamber and a thick-walled conducting plastic chamber have been produced. The thin-walled chamber shows a variation in its sensitivity of only 3 percent for the range of qualities generated by 60 to 250 kV x rays. The thick-walled chamber is useful for energies as high as those for cobalt 60 and has a variation of sensitivity of about 5 percent for qualities generated by 60 kV x rays through those from cobalt 60 gamma rays.

Future international exposure comparisons will be coordinated by the International Bureau of Weights and Measures (BIPM) in Sevres, France. To assist them in maintaining uniformity of standards through the world, NBS is loaning them some of the plastic chambers. In addition, BIPM, together with the national laboratories, is endeavoring to reduce the uncertainty of the standards. As a first step in this direction a direct comparison of 3 or 4 low voltage (10 to 60 kV) standards is scheduled for the fall of 1965. This comparison will include a detailed investigation of all of the correction factors required for such determination and will thus necessitate active participation by all national laboratories represented.

The NBS has a set of ionization chambers which are available on a loan basis to measure total x-ray beam energy between 6 and 300 MeV. They are intended for use with x-ray beams of low to moderate intensities (from a minimum power of 10 microwatts to a maximum power density of 1 milliwatt/cm^2), and are fully described in NBS Monograph 48 [38]. They were calibrated in two experiments at NBS [39-40]. Additional calibrations have been obtained indirectly by comparison with replicas of other chambers calibrated in other laboratories, and by direct experiments at the Max Planck Institute for Biophysics [41] and at the University of Illinois [42]. As a result, the calibration has an uncertainty less than ±0.5 percent between 20 and 150 MeV, which rises to ±1.8 percent at 6 MeV and to ±1.3 percent at 300 MeV. The most recent calibrations and errors were published by Pruitt and Domen [43].

One of these ionization chambers was transported to Europe in 1959 and compared with replicas in Paris, Frankfurt, Zurich, and Ljubljana [44]. These comparisons not only served to show that with sufficient care a replica chamber could be constructed with a calibration within a few tenths of 1 percent of that of the original but also transferred the NBS calibrations to several laboratories in Europe. In addition, the calibrations have more recently been transferred by direct comparison to Tohoku University, Sendai, Japan, and to the Radiophysics Institute, Stockholm, Sweden.

4. Nuclear Data Compilation and Evaluation

(a) The Nuclear Data Group under K. Way (Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee) is the most comprehensive of the nuclear data compilation efforts. The current form of data presentation is the loose-leaf Nuclear Data Sheets [45] which are periodically updated. (Subscriptions are handled by the National Academy of Sciences Printing and Publishing Office, 2101 Constitution Avenue, N. W., Washington, D. C.) The data sheets cover nuclear level parameters, nuclear decay properties, reactions, moments, isotopic abundances, and other properties. Earlier publications include the Nuclear Data Tables [46,47] containing data collections systematized according to some specific nuclear property (e.g., Q-values, reaction graphs). A newsletter, prepared by K. Way, entitled, "World-Wide News of Compilations in Nuclear Physics" is available.

(b) BNL Sigma Center. This Center collects, stores, and evaluates neutron cross sections. BNL-325, 2nd ed., was published in 1958. A first supplement was published in 1960. A three volume second supplement is being prepared. Vol. I, Z=1-20 appeared in May 1964. A second volume for Z=88-96 is in press. Data on angular distributions is contained in BNL-400, 2nd ed., October 1962. A tape storage and retrieval program (SCISRS) has been developed and all cross section data are being stored in this format and is available to those who need the data.

The cross section evaluation work of the Center involves neutron cross sections and other nuclear data of use to reactor physicists. The Center has issued since 1960 eight Newsletters and many other reports on cross sections and is preparing a tape storage and retrieval program (ENDF) for reactor cross sections. A computer code for calculating optical model cross sections (ABACUS II) has been developed and is available upon request. Typical Newsletters are on such topics as (n,2n) cross sections, consistent sets of 2200 m/sec cross sections, computations of angular distributions, inelastic cross sections, and the like.

Further information can be obtained from Murrey Goldberg, Sigma Center, Brookhaven National Laboratory, Upton, Long Island, New York. The compilations are now available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402 (48,49). The Newsletters are available from the Clearinghouse for Federal, Scientific and Technical Information, National Bureau of Standards, U. S. Dept. of Commerce, Springfield, Virginia.

(c) Tabulated Differential Neutron Cross Sections compiled by Robert J. Howerton are available from the University of California, Lawrence, California [50].

(d) CINDA (Computer Index Neutron Data) is a bibliographical index of information concerning microscopic neutron cross sections and allied data for specific elements and isotopes. The listing consists of the targets, quantity reported, range of incident neutron energy, and reference information. The authors of this compilation are Herbert Goldstein, Columbia University, and Melvin H. Kalos, Courant Institute, New York University and United Corporation [51]. Copies of this report may be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Virginia, and from the Division of Technical Information Extension, U.S. Atomic Energy Commission, P.O.Box 62, Oak Ridge, Tennessee.

(e) Photonuclear Data Compilation - A program of compilation and evaluation of photonuclear reaction data is in progress under E. G. Fuller of NBS. A first step in this program has been a systematic search of the nuclear physics literature from 1956 to data. The results have been abstracted from experimental papers which dealt with nuclear reactions initiated by photons or electrons (e.g., (γ,γ), (γ,n), (e,e'), $(e,e'p)$, or with the inverse process in which a ground state gamma ray is emitted following heavy particle capture (e.g., (p,γ_0)). The first publication of this group will be a quantitative bibliography of photonuclear reactions in which the following information is listed: element, reaction, type of cross section information,

excitation energy range, source type and energy range, detector description (detected particle energy range and angular distribution), and additional remarks characterizing the experiment. This bibliography should be available May 1, 1965. This group eventually hopes to compile a set of "best values" for photonuclear cross sections for different reactions for different elements. Further information can be had from J. S. O'Connell, Radiation Physics Division, National Bureau of Standards, Washington, D. C. 20234.

(f) Charged-Particle Cross Sections - A 400-page volume of graphs and tables on charged-particle cross sections for manganese, iron, and cobalt, compiled by an Oak Ridge group consisting of F. K. McGowan, W. T. Milner, and H. J. Kim is available [52]. Cross sections as function of bombarding-particle energy and of emitted-particle angle, and emitted-particle polarization as function of angle are presented for the three elements mentioned above. Later volumes will cover the region from cobalt through uranium. Reports LA-2014 and LA-2424 [53,54] will be brought up to date by the ORNL group through supplements similar in style to the present volume [55].

(g) Energy-Levels of Light Nuclei (He^5 to Ne^{24}) are compiled by F. Ajzenberg-Selove (Haverford College, Haverford, Pennsylvania) and T. Lauritsen (California Institute of Technology, Pasadena, California). The last complete review was published in 1959 [56]. An addendum was issued by the Nuclear Data Group in May 1962 [57].

(h) National Standard Reference Data System - The general problem of processing and evaluating technical information has been under review by a number of executive and congressional groups. One output of these reviews was the promulgation of a Federal policy in June 1963 in which a National Standard Reference Data System was established and in which the National Bureau of Standards was given the responsibility for its administration. The general objective of this system is to coordinate and integrate existing data compilation and evaluation activities into a systematic program, supplementing and expanding technical coverage when necessary, establishing and maintaining standards for the output of the various groups, and providing a mechanism for the dissemination of the output as required. The program will be based on a decentralized operation conducted across the country in many organizations by many individuals and groups, with central coordination managed by the National Bureau of Standards. Account is to be taken of all existing activities, and no attempt will be made to take over direct operational management of existing groups, nor will new activities be initiated in fields now adequately covered.

An initial preliminary survey by E. L. Brady, Chief of the NSRDS program, indicated that the field of nuclear physics is relatively well covered by means of data compilation and evaluation programs and that perhaps only a few specific activities need to be added or expanded. Under the financial sponsorship of the AEC, a number of continuing activities have been in operation for some years, producing critically evaluated compilations of values of nuclear properties, reaction cross sections, and reactor physics data. Tentative conclusions from the preliminary survey are that the present effort on charged particle cross sections needs to be expanded, that the various nuclear cross section compilation groups could benefit by better coordination of their efforts and better definition of their individual responsibilities, and that the use of machine techniques by all groups should be investigated. It is to be expected that the detailed survey to be conducted will reveal additional needs for new or expanded activities.

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6. National Committee on Radiation Protection and Measurements - NBS Handbook 72, Measurement of Neutron Flux and Spectra for Physical and Biological Applications. (U. S. Government Printing Office, Washington, D. C. 20402) p. 66.

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11. K. W. Geiger, The status of the Canadian neutron standard. Can. J. Phys. 38, 569 (1960).

12. The descriptions, conditions, charges, and instructions for obtaining calibration services and standard materials from the National Bureau of Standards are to be found in two NBS publications entitled: NBS Miscellaneous Publications #241, Standard Materials, and #250, Calibration and Test Services. These publications are obtainable from the U. S. Government Printing Office, Washington, D. C. 20402.

Updated excerpts from these publications are to be found in Tables 2, 3, and 4 of the present report. General questions regarding the availability of standards, services, and research in nuclear and radiation physics are to be directed to the Chief, Radiation Physics Division, National Bureau of Standards, Washington, D. C. 20234.

13. The boric acid standards can be obtained in the United States by writing to Dr. R. S. Caswell, National Bureau of Standards, Washington, D. C. 20234. Reference should be made to the detailed description of the standards in Table 2d.

14. F. T. Gould, T. I. Taylor, W. W. Havens, Jr., B. M. Rustad, and E. Melkonian, Long wavelength crystal spectrometer and the neutron absorption cross sections of gold and boron. Nuclear Science and Engineering 8, 453 (1960).

15. A recent description of the special targets and foils available from Oak Ridge are to be found in Table 2g. Any special requirements will be considered by the ORNL group by directing communications to Mr. E. Kobisk, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

16. International Commission on Radiological Units and Measurements - NBS Handbook 85, Physical Aspects of Irradiation. (U.S.Government Printing Office, Washington, D. C. 20402) p. 48.

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Table 1a

Standard Neutron Source Data

Name and address of source location		National Bureau of Standards, Washington, D.C.
Name of scientist in charge		V. Spiegel, Jr.
Type of source. Identification numbers, composition, dimensions		Radium-Beryllium (γ,n), designated NBS-I. Radium source material enclosed in platinum-iridium capsule 0.2 mm thick, in shape of right circular cylinder 0.84 cm diameter, 0.86 cm height. Capsule is enclosed in beryllium sphere 4.00 cm diameter.
Absolute calibration	Date	June 1961
	Methods	Heavy-water manganous-sulfate bath, light-water manganous sulfate bath, calibrated manganese and indium foils in a light water bath.
	Results and accuracy*	$1.25_7 \times 10^6$ n/sec ±1 percent (June 1961), weighted average of 3 methods above. Heavy-water bath $1.25_2 \times 10^6$ ± 1.1 percent. Light-water bath $1.25_6 \times 10^6$ ± 2 percent. Foils in bath $1.24_2 \times 10^6$ ± 3 percent. (Errors are sum of standard error and systematic error)
	Where published?	Noyce, Mosburg, Garfinkel, Caswell, Jour. Nucl. Energy A/B 17, 313 (1963); DeJuren and Chin, Jour. Research Nat'l. Bur Stds. 40, 311 (1955); DeJuren, Padgett, and Curtiss, J. Res. NBS 40, 63 (1955).
Neutron spectrum determination	Date	
	Method	
	Results and accuracy*	Presumably similar to spectrum of companion source NBS-11.
	Where published?	

Table 1b

Standard Neutron Source Data

Name and address of source location		National Bureau of Standards, Washington, D.C.
Name of scientist in charge		V. Spiegel, Jr.
Type of source. Identification numbers, composition, dimensions		Radium-Beryllium (γ,n), designated NBS-II. The radium source material is enclosed first in a platinum-iridium capsule of 0.2 mm thickness and then in a monel capsule of thickness 1.0 mm. in shape of a right circular cylinder 1.005 cm diam by 1.018 cm. height. Capsule is enclosed in a beryllium sphere 4.00 cm diameter.
Absolute calibration	Date	1958
	Method	Graphite sphere with BF_3 thermal neutron counters
	Results and Accuracy	An absolute source strength of 1.21×10^6 neutrons/sec with an error of ± 2 percent quoted for the detector efficiency.
	Where published?	J. H. Gibbons and R. L. Macklin, Phys. Rev. 114, 571 (1959)
Relative calibration	Date	1959
	Methods	Activation of manganous sulfate bath
	Results and Accuracy	Relative source strength to NBS-I is $0.939_3 \pm .001_7$. This gives absolute source strength of $1.18_1 \times 10^6$ neutrons/sec ± 1.1 percent (standard error plus systematic error) as of June 1961.
	Where published?	E. R. Mosburg, Jr., J. Research Nat'l Bur. Stds. 62, 189 (1959)
Neutron spectrum determination	Methods	Cloud Chamber, Double Moderator Neutron Dosimeter
	Results and Accuracy	Maximum neutron energy 700 keV, Spectrum reported in NBS Handbook 85, page 58 or NBS Handbook 72, page 66. Cloud chamber gives 0.31 MeV average energy while moderation method gives 0.2 MeV.
	Where published?	Eggler and Hughes ANL 4476 (1950); DePangher, Nucl, Instr. Method 5, 61 (1959)

Table 1c

Comparison of NBS Neutron Sources With Sources from Other Institutes

Description of source to which the NBS source has been compared	Type Identification numbers composition, dimensions	This page refers to a number of comparisons made at Harwell in 1955 by R. Richmond, referred to present value for NBS source II.
	Name and address of Institute	See below
	Neutron output and accuracy. Method of measurement	See below
Date of comparison		1955
Method		Activation of manganous sulfate bath

Result and accuracy Laboratory X	Source strength laboratory standard Q_X (neutrons/sec)	Ratio Q_X/Q_{NBS} for same source
Oxford (RdTh-D_2O)	$6.18 \times 10^4 \pm 1.6\%$	0.996
Basel (B2) Ra-Be(α,n)	$1.515 \times 10^6 \pm 2.8\%$	.973
Harwell Ra-Be(α,n)	$9.66 \times 10^6 \pm 4.5\%$ (1951)	1.060
Stockholm RA-Be(α,n)	$2.65 \times 10^6 \pm 2\%$ (Oct. 1954)	1.002

Where published?	R. Richmond Progr. in Nucl. Energy, Series I, Phys, and Math, II, 165 (1958)

Table 1d

Comparisons of NBS Neutron Sources

With Sources from Other Institutes

Description of source to which the NBS source has been	Type Identification numbers composition, dimensions	RA-Be(α,n)
	Name and address of institute	A. B. Atomenergi, Stockholm, Sweden
	Neutron output and accuracy*. Method of measurement.	$2.65 \times 10^6 \pm 2\%$ (neutrons/sec) (Oct. 1954). Various methods (see reference).
Date of comparison		May 1957
Method		Baron counters in water or boric acid solution.
Result and accuracy*		1.167×10^6 neutron sec ± 3% inter-comparison error (strength for NBS-II) Ratio Stockholm/NBS for same source = 0.986 ± 3%
Where published?		K.-E. Larsson, J. Nuclear Energy 6, 322 (1958)

Table 1e

Comparisons of NBS Neutron Sources

With Sources from Other Institutes

Description of source to which the NBS source has been compared.	Type Identification numbers, composition, dimensions	Ra-Be(α,n) NRC source N-200-1
	Name and address of institute	National Research Council Ottawa, Canada
	Neutron output and accuracy. Method of measurement.	$(3.20_8 \pm 0.05) \times 10^6$ n/sec (July 1958)
Date of comparison		July 1959
Method		Activation of $MnSO_4$ bath
Result and accuracy		Canadian value for NBS-II is 1.176×10^6 neutrons/sec ± 1 percent (July 1959) corrected to June 1961, this is 1.175×10^6 neutrons/sec. This gives ratio NRC/NBS for same source = 0.995
Where published?		K. W. Geiger, Can. J. Physics Vol. 38 569 (1960)

Table 1f

Comparison of NBS Neutron Sources

With Sources from Other Institutes

Description of source to which the NBS source has been compared.	Type Identification numbers composition, dimensions	Ra-Be(γ,n) NPL Source 2C
	Name and address of institute	National Physical Laboratory, Teddington, England.
	Neutron output and accuracy. Method of measurement.	1.664×10^5 neutrons/sec ± 2 percent, manganous sulfate bath
Date of comparison		November 1960
Method		Activation of manganous sulfate bath
Result and accuracy		1.686×10^5 neutrons/sec. Intercomparison uncertainty 0.24%. Ratio NPL/NBS 0.988 for same source.
Where published?		Not published

Table 2a

Neutron Sources

Item	Description	Fee
204.701a	Determination of ratio of neutron emission rate of unknown source to primary standard in $MnSO_4$ bath or graphite column	$385.00

Table 2b

Neutron Instruments

Item	Description	Fee
204.702a	Calibration of a set (one to three) of thermal neutron dosimeters	$78.00

Table 2c

Neutron Irradiation of Foils

Item	Description	Fee
204.703a	Activation of a set (one to four) of foils in the NBS standard thermal neutron flux geometry	$59.00

Table 2d

Boric Acid Standard

The Nuclear Cross Section Advisory Group of the United States Atomic Energy Commission and the European American Nuclear Data Committee have obtained the cooperation of the Central Bureau of Nuclear Measurements in Geel, Belgium, and the National Bureau of Standards in the United States in acquiring stocks of standard H_3BO_3. These committees announce the availability of the stocks and emphasize the desirability of measuring boron neutron cross sections with boron from these standard stock materials.

The determination of many neutron cross sections is based on the thermal cross section of the B^{10} (n,α) reaction which is now known to 0.3%. However, the B^{10} isotopic content of boron found in nature varies widely. For example, the Central Bureau of Nuclear Measurements of EURATOM at Geel, Belgium, has recently investigated samples of standard boron stocks taken from the various countries and has found that while most of the standard boron samples used have about 19.8% B^{10}, the standard samples used at Fontenay-aux-Roses, France, and Harwell, England, contain 20.1% B^{10}. The results of these investigations are presented in a European American Nuclear Data Report, EANDC(E)-36, which is available from the Central Bureau of Nuclear Measurements, Geel, Belgium.

These stocks at the CBNM and NBS have been thoroughly analyzed both isotopically and chemically. The stock at the NBS is the lot called Argonne II, which was originally prepared for the Argonne National Laboratory and was analyzed at Argonne. This stock is being distributed at present with no further analysis by NBS. The results of the Argonne analysis will, however, be supplied with the NBS samples. Work is now underway which will lead to NBS certification of this material. Both the CBNM and NBS stocks have a boron 10 content of about 19.8 atomic percent and both have been checked at CBNM and have been found identical in isotopic composition to within ± 0.02 atomic percent. At the present time the CBNM has a stock of 100 kilograms and the NBS has 300 kilograms of this H_3BO_3. If the results to be obtained justify the effort, the Central Bureau of Nuclear Measurements will supply standardized solutions and films with a certificate giving details, such as isotopic and chemical composition.

European scientists should write to:

Dr. G. H. Debus
Head of Mass Spectrometry Group and of Target and Sample Preparation Lab.
Central Bureau of Nuclear Measurements
EURATOM
Steenweg naar Retie
Geel, Belgium

In the United States scientists should write to:

Dr. R. S. Caswell
Chief, Neutron Physics Section
National Bureau of Standards
Washington, D. C. 20234

Table 2d (Cont'd)

NBS Boric Acid Sample Specifications*

			Ref.
CHEMICAL			
H_3BO_3	99.5	%	1
Insoluble in alcohol	Pass ACS Test		
Non volatile with methanol	0.02	%	
Chloride	0.001	%	
Phosphate	0.0002	%	
Sulphate	0.003	%	
Arsenic	0.00005	%	
Calcium	0.002	%	
Heavy Metals (as Pb)	0.0005	%	
Iron	0.0003	%	
ISOTOPIC			
Per cent B^{10}	19.84±0.04	%	2
	19.81±0.02		2
	19.7±0.17		3
	19.8±0.1		4
	19.8±0.1		5
CROSS SECTION AT 0.0253 eV.			
Cross section at 0.0253 eV.	761±3	barns	3
	764±3		6
	758±4		7
	757±6		8

*This sample is from the lot of boric acid known as New Argonne Standard Boron, Argonne II, and ANL-BNL boron.

Table 2d (Cont'd)

1. J. T. Baker Chemical Co., Phillipsburg, N. J. Analysis of Lot 92511.

2. G. H. Debus et al. EANDC(E) 36 and Reactor Sci. and Tech. 17 349 (1963).

3. G. I. Safford et al. Phys. Rev. 119 1291 (1960) and Nuclear Sci. and Eng. 9 132 (1961).

4. F. T. Gould et al. Bull. Am. Phys. Soc. (Ser. 11) 2 42 (1957).

5. Haas et al. KAPL-2062 (1959) (unpublished).

6. F. T. Gould et al. Nuclear Sci. and Eng. 8 453 (1960).

7. J. W. Meadows and J. F. Whalen Nuclear Sci. and Eng. 9 132 (1961).

8. H. W. Schmitt et al. Nuclear Phys. 17 109 (1960).

Table 2e

Uranium Oxide Isotopic Standard

	Uranium Oxide (U_3O_8)	U-234	U-235	U-236	U-238	U	$ Price/Gram
U-005	U-235-depleted	0.0023	0.483	0.0046	99.51	1.0g	20.50
U-010	U-235-enriched	.0054	.991	.0067	98.99	1.0	20.50
U-015	U-235-enriched	.009	1.51	.016	98.47	1.0	20.50
U-020	U-235-enriched	.012	2.01	.016	97.96	1.0	21.00
U-030	U-235-enriched	.018	3.01	.020	96.95	1.0	21.00
U-050	U-235-enriched	.028	4.95	.048	94.98	1.0	21.00
U-100	U-235-enriched	.067	10.07	.038	89.82	1.0	22.00
U-150	U-235-enriched	.099	15.13	.065	84.71	1.0	23.00
U-200	U-235-enriched	.125	19.80	.209	79.86	1.0	23.50
U-350	U-235-enriched	.249	34.89	.170	64.69	1.0	26.50
U-500	U-235-enriched	.512	49.38	.0755	50.03	1.0	29.00
U-750	U-235-enriched	.593	75.12	.252	24.03	1.0	33.50
U-800	U-235-enriched	.660	80.07	.246	19.02	1.0	34.00
U-850	U-235-enriched	.64	84.99	.37	14.00	1.0	35.00
U-900	U-235-enriched	.77	90.10	.33	8.80	1.0	36.00
U-930	U-235-enriched	1.08	93.27	.205	5.44	1.0	37.50

Standards are available to AEC contractors, AEC or State licensees, and foreign governments which have entered an Agreement for Cooperation with the U.S. Government concerning the Civil Uses of Atomic Energy. The purchase request for these standards must be made on special forms obtainable free of charge from the Department of Commerce, National Bureau of Standards, Reference 310.04, Washington, D.C. 20234.

Domestic orders must be placed on Form NBS-285 and sent in duplicate to the National Bureau of Standards. Uranium standards will be shipped by prepaid parcel post. The plutonium standards will be shipped by Express, collect, from Washington.

Foreign orders must be placed on Form NBS-285A and sent in quadruplicate to the Division of International Affairs, U. S. Atomic Energy Commission, Washington, D. C. 20545. Uranium standards can be shipped post paid from the National Bureau of Standards, by International Parcel Post. Plutonium standards will be packed for overseas shipment and, unless otherwise advised, will be shipped by air freight, uninsured, FOB, Washington, transportation costs collect. Remittances in payment of foreign orders must be made payable to the National Bureau of Standards and are required in advance. These remittances must be drawn on a bank in the United States and payable at the standard rate of United States currency.

Table 2f

PLUTONIUM SULFATE ISOTOPIC STANDARD

Isotope	Pu^{239}	Pu^{240}	1/ Pu^{241}	Pu^{242}
Atom Percent	91.365 ±0.010	7.907 ±0.010	0.695 ±0.002	0.0330 ±0.0003
Weight Percent	91.329	7.937	0.700	0.0334

1/ The value for plutonium-241 will slowly (half-life 13 years) decrease, and the other values increase proportionately, because of the decay of plutonium-241 to americium-241. The value given is for June 1, 1964, and was obtained on samples from which the americium was removed. Satisfactory values averaging 11.55 for the atom ratio plutonium-239 to plutonium-240 were obtained without the removal of americium.

The sample was prepared in the form of plutonium sulfate tetrahydrate from high-purity metal at the New Brunswick Laboratory of the Atomic Energy Commission. The values given above were obtained from mass-spectrometry measurements at the National Bureau of Standards by Ernest L. Garner and William R. Shields, using chemical preparations by Lawrence A. Machlan, Rolf A. Paulson, and Martha S. Richmond. The values were calculated from measurements made on a multiplier-equipped spectrometer of the ratios Pu-239 to Pu-240, Pu-241 to Pu-240, and Pu-242 to Pu-240, corrected for discrimination effects from measurements under similar conditions on known mixtures of uranium isotopes. The limits indicated were calculated from the data obtained at NBS and are for a 95-percent confidence level for a single determination. They are dependent on uranium and plutonium exhibiting similar behavior since high-purity plutonium isotopes were not available in quantity to prepare synthetic mixtures.

Table 2g

Special Targets and Foils

Many of the measurements made to obtain nuclear data require use of thin foils and special targets fabricated from isotopes. The ORNL Isotopes Development Center offers enriched isotope foils and targets to meet the requirements of experimenters engaged in this vital research.

Various fabrication techniques are used, depending upon the physical properties of the elements involved. The major methods include vacuum evaporation, rolling, electrolytic deposition, pressing, and casting. Vapor plating is occasionally used to reduce compounds to elemental form for further processing by rolling or evaporation. In the case of enriched C^{14} targets, acetylene prepared with C^{14} is polymerized in a glow discharge produced between two plates. These plates also serve as a backing for the deposit.

Evaporated foils are prepared on metal plates up to 2 x 3 in. This backing material can be adjusted in thickness, shape, and composition to meet the parameters of the experiment.

Self-supported foils prepared by evaporation are often deposited on glass plates in sizes up to $3\frac{1}{4} \times 4$ in. The glass plates are coated with a parting agent which permits stripping of the film from the glass. In some cases the plates are shipped without stripping to permit transport of fragile films, and stripping in a water bath is carried out at the laboratory of the experimenter. Normal carbon foils prepared in this manner can be used without further treatment, or used as backing for enriched isotopes which are amenable to the evaporation technique.

The size of rolled foils has been standardized at 1 x 1 in. In special cases larger sizes can be prepared. Pressed and cast targets range from $\frac{1}{4}$ to $2\frac{1}{4}$ in. in diameter in increments of $\frac{1}{4}$ in. Reactive materials are often encapsulated to permit normal handling.

The cost for fabrication varies from $125 to $150 for standard forms. Quotations will be provided for special shapes after a review of specifications.

Mass and spectrochemical analyses of the isotopic material used in the fabrication are included with each shipment. Foils prepared by evaporation are produced to a tolerance of ±20%, rolled foils to a tolerance of ±5%.

Table 2g (cont'd)

The following table provides thickness range, method of preparation and type of backing available:

Element	Range of Thickness	Method of Preparation	Backing
H (as hydride of Zr, Y or Ti)	100 to 5000 $\mu g/cm^2$	Zr, Y, Ti on 10-mil Pt followed by H^3 sorption	Metal
D (as deuterated polyethylene)	>0.2 mil	Pressing or blowing	Self-supporting
Li	1 mg/cm^2 to any cast size	Casting or rolling	Self-supporting
Li (as LiH)	20 to 500 ug/cm^2	Vacuum evaporation	Carbon
Be	25 to 500 $\mu g/cm^2$	Vacuum evaporation	Carbon
B	20 to 200 $\mu g/cm^2$	Vacuum evaporation	Self-supporting or metal
	500 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal
C Normal Isotopic	10 to 100 $\mu g/cm^2$	Vacuum evaporation Polymerization of acetylene	Self-supporting Metal
F(as fluoride)	25 to 500 $\mu g/cm^2$	Vacuum evaporation	Metal
Na	7.5 mg/cm^2 to any cast size	Rolling or casting	Self-supporting
Mg	5 to 8000 $\mu g/cm^2$	Vacuum evaporation	Carbon
Al	5 to 12,000 $\mu g/cm^2$	Vacuum evaporation	Metal
Si	30 to 100 $\mu g/cm^2$	Vacuum evaporation	Self-supporting
	10 to 100 $\mu g/cm^2$-	Vacuum evaporation	Metal
S	5 mg/cm^2 up	Pressing or casting	Self-supporting
Cl (as compound)	5 mg/cm^2 up	Vacuum evaporation	Metal
		Pressing or casting	Self-supporting

Table 2g (cont'd)

Element	Range of Thickness	Method of Preparation	Backing
K	7.5 mg/cm^2 to any cast size	Rolling or Casting	Self-supporting
Ca	1 mg/cm^2 up	Rolling	Self-supporting
Sc	1 mg/cm^2 up	Rolling	Self-supporting
Ti	1 mg/cm^2 up	Rolling	Self-supporting
V	1 mg/cm^2 up	Rolling	Self-supporting
Cr	10 to 5000 μg/cm^2	Electrolytic deposition	Metal
Fe, Co, & Ni	1 mg/cm^2 up	Rolling	Self-supporting
	800 mg/cm^2 up	Casting	Self-supporting
	10 to 1000 μg/cm^2	Electrolytic deposition	Metal
			Ni - Self-supporting (100 to 1000 μg/cm^2)
Cu	1 mg/cm^2 up	Rolling	Self-supporting
	10 to 1000 μg/cm^2	Electrolytic deposition	Metal
	200 μg/cm^2 up	Vacuum evaporation	Self-supporting
Zn	1 mg/cm^2 up	Rolling	Self-supporting
	10 to 1000 μg/cm^2	Electrolytic deposition	Metal
Ge	10 to 200 μg/cm^2	Vacuum evaporation	Metal
As	10 to 2000 μg/cm^2	Vacuum evaporation	Metal
Se	300 to 5000 μg/cm^2	Vacuum evaporation	Self-supporting
	10 to 5000 μg/cm^2	Vacuum evaporation	Metal

Table 2g (cont'd)

Element	Range of Thickness	Method of Preparation	Backing
Br (as bromide)	5 mg/cm^2 up	Vacuum evaporation	Metal
		Casting	Self-supporting
Rb (salt)	10 to 1000 μg/cm^2	Vacuum evaporation	Metal
	40 mils up	Pressing	Self-supporting
Y	10 to 5000 μg/cm^2	Vacuum evaporation	Metal
Zr	1 mg/cm^2 up	Rolling	Self-supporting
	10 to 5000 'g/cm^2	Vacuum evaporation	Metal
Nb	2 mg/cm^2 up	Rolling	Self-supporting
Mo	10 to 1000 μg/cm^2	Vacuum evaporation	Metal
Tc	10 to 1000 μg/cm^2	Vacuum evaporation	Metal
Pd	1 mg/cm^2 up	Rolling	Self-supporting
Ag	1 mg/cm^2 up	Rolling	Self-supporting
	100 to 5000 μg/cm^2	Vacuum evaporation	Self-supporting
	10 to 1000 μg/cm^2	Vacuum evaporation	Metal
	40 mils up	Casting or pressing	Self-supporting
Cd	1 mg/cm^2 up	Rolling	Self-supporting
In	5 mg/cm^2 up	Rolling	Self-supporting
Sn	3 mg/cm^2 up	Rolling	Self-supporting
	10 to 1000 μg/cm^2	Vacuum evaporation	Metal
	0.5 to 3 mg/cm^2	Vacuum evaporation	Self-supporting
Sb	10 to 1000 μg/cm^2	Vacuum evaporation	Metal

Table 2g (cont'd)

Element	Range of Thickness	Method of Preparation	Backing
Te	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal or carbon
Cs (salt)	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal
Ba (salt)	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal
La (metal) and rare earth (as oxides)	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal or carbon
Ta	2 mg/cm^2 up	Rolling	Self-supporting
	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal
W	In Cu matrix - > 2 mg/cm^2	Rolling or pressing	Self-supporting in Cu
Pt	3 mg/cm^2 up	Rolling	Self-supporting
Hg	1 to 4 mg/cm^2	Electrolytic deposition	Gold
Tl	8 mg/cm^2 up	Rolling	Self-supporting
Pb	8 mg/cm^2 up	Rolling	Self-supporting
	1 to 8 mg/cm^2	Vacuum evaporation	Self-supporting
	10 to 1000 $\mu g/cm^2$	Vacuum evaporation	Metal

Table 3a

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Radioactivity Standard Samples

November, 1964

PURCHASING AND SHIPPING INFORMATION

U.S.A. AND CANADA: Radioactivity standards are shipped express collect only to destinations in the United States and Canada.

OTHER COUNTRIES: In the case of shipments to other countries, consignee should apply to the National Bureau of Standards for pro forma invoices, and establish credit in advance at any bank in the United States, or send payment by international money order or UNESCO coupons, to cover the cost of the standards. Consignee can either appoint an agent in the United States to handle shipments abroad, or shipments can be made by air freight or express (shipping charges collect) subject to the laws and regulations of the importing country.

GENERAL INFORMATION

CERTIFICATION: A certificate containing pertinent information is sent under separate cover. Information concerning the standard appears on the standard or container.

PRICES: Prices of certain standard samples may change as current stocks are depleted and are replaced by new issues. In these instances, buyers will be notified before orders are filled.

ALPHA STANDARDS

Sample No.	Radionuclide	Approximate α-Particle Emission Rate in 2π Geometry	Price per Sample	Footnote
4900	Polonium-210	100 αps	$50.00	(a)(c)
4901	Polonium-210	250 αps	50.00	(a)(c)
4902	Polonium-210	500 αps	50.00	(a)(c)
4904-A	Americium-241	20 αps	60.00	(b)

(a) Samples Nos. 4900, 4901, and 4902 consist of practically weightless deposits of polonium-210 on monel disks 2.54 cm in diameter and 0.16 cm thick. The activity per sample is restricted to a 0.3 cm-diameter area in the center of the disk.

(b) Sample No. 4904-A consists of a practically weightless deposit of americium-241 on a platinum foil 1.27 cm in diameter, 0.015 cm thick. This foil is cemented onto a monel disk 2.54 cm in diameter and 0.16 cm thick. The activity is restricted to a 0.3 cm-diameter area in the center of the foil. This sample can now be distributed under the general licensing provisions of the Atomic Energy Act of 1954. (Please refer to Amendments to Title 10, Chapter 1, Part 30, Licensing of By-Product Material, General Licenses for Americium-241, 29 Federal Register 5882, May 5, 1964).

(c) Total activity of these standards is such that they may be ordered under the general licensing provisions of the Atomic Energy Act of 1954.

BETA, GAMMA AND ELECTRON-CAPTURE SOLUTION STANDARDS (e)

Sample No.	Radionuclide	Calibration Radiation (d)	Approximate Activity or Emission Rate at Time of Calibration (month, year)	Approximate Weight of Solution	Price per Sample	Footnote
4921-C	Sodium-22	β^+	1×10^4 β^+ ps/g (8/64)	3 g	$37.00	
4922-D	Sodium-22	γ	1×10^5 β^+ ps/g (6/64)	5 g	37.00	
4924	Carbon-14 (water)	β^-	1×10^3 dps/g (7/58)	25 g	32.00	(f)
4925	Carbon-14 (toluene)	β^-	2×10^4 dps/g (7/58)	3 g	32.00	(f)

Table 3b

BETA, GAMMA AND ELECTRON-CAPTURE SOLUTION STANDARDS (e)

Sample No.	Radionuclide	Calibration Radiation (d)	Approximate Activity or Emission Rate at Time of Calibration (month, year)	Approximate Weight of Solution	Price per Sample	Footnote
4926	Hydrogen-3 (water)	β^-	9×10^3 dps/g (9/61)	25 g	$45.00	(f)
4927	Hydrogen-3 (water)	β^-	9×10^5 dps/g (9/61)	3 g	45.00	(f)
4929-B	Iron-55	X	2×10^4 dps/g (5/64)	3 g	46.00	(f)
4932-C	Mercury-203	γ	3×10^6 dps/g (5/64)	5 g	49.00	(g)
4940	Promethium-147	β^-	8×10^4 dps/g (5/61)	3 g	40.00	(f)
4941-B	Cobalt-57	γ	3×10^4 dps/g (7/62)	5 g	24.00	(f)
4943	Chlorine-36	β^-	1×10^4 β^-ps/g (1962)	3 g	26.00	(f)
4944-B	Iodine-125	X	7×10^4 dps/g (4/64)	5 g	50.00	(f)
4945-B	Strontium-89	β^-	3×10^3 dps/g (9/64)	3 g	30.00	(f)
4946	Cerium-141	β^-			Temporarily Out of Stock	
4947	Hydrogen-3 (toluene)	β^-	3×10^5 dps/g (2/64)	4 g	30.00	(f)

(d) This is the radiation for which the nuclide is intended to be used as a standard.

(e) Samples are contained in flame-sealed glass ampoules.

(f) Total activity of these standards is such that they may be ordered singly under the general licensing provisions of the Atomic Energy Act of 1954. (Please refer to Federal Register, Volume 21, p. 213, January 11, 1956.)

(g) These standards can be issued only under the special licensing provisions of the Atomic Energy Act of 1954, and it is therefore required that a copy of the purchaser's current AEC By-Product Material License be on file at the National Bureau of Standards.

BETA GAS STANDARD

Sample No.	Radionuclide	Calibration Radiation (d)	Approximate Activity at Time of Calibration (month, year)	Volume	Price per Sample	Footnote
4935-B	Krypton-85	β^-	6×10^7 dps per gram mole (10/62)	10 ml	$23.00	(h)

(h) Sample No. 4935-B contains approximately 10 ml of krypton-85 in inert krypton at a pressure of approximately one atmosphere in a break-seal glass ampoule.

POINT-SOURCE GAMMA-RAY STANDARDS (i)

Sample No.	Radionuclide	Approximate Emission Rate at Time of Calibration (month, year)	Price per Sample	Footnote
4991	Sodium-22	1×10^4 γps (12/59)	$32.00	(f)
4992-B	Zinc-65	4×10^4 γps (1/62)	30.00	(f)
4997-C	Manganese-54	5×10^4 γps (1/64)	54.00	(f)
4998	Yttrium-88		Temporarily Out of Stock	
4999-B	Cerium-139	2×10^4 γps (6/64)	45.00	(f)
4200	Cesium-137	5×10^4 γps (8/63)	46.00	(f)

(i) These standards are deposited between two layers of polyester tape approximately 0.006 cm thick and mounted on aluminum annuli, 0.8 cm wide and 5.5 cm outside diameter.

Table 3c

RADIUM ROCK SAMPLES (j)

Sample No.	Rock	Average radium content (picogram of radium per gram of rock)	Price per Sample
4978	Columbia River Basalt	0.33 ± 0.03	$11.00
4982	Gabbro-Diorite	0.18 ± 0.02	11.00
4984	Triassic Diabase	0.18 ± 0.03	11.00

(j) Each sample consists of 100 g of pulverized rock taken from bulk material analyzed for radium content. Petrographic data and the chemical analysis of a specimen of the rock is also given in a certificate accompanying each sample. These samples are shipped parcel post prepaid.

RADIUM SOLUTION STANDARDS (FOR RADON ANALYSIS) (e)

Sample No.	Radium Content (in grams) as of 1956	Approximate Weight	Price per Sample
4950-A	10^{-9}	100 g	$42.00
4951	10^{-11}	100 g	32.00
4952	Blank Solution	100 g	7.50

RADIUM GAMMA-RAY SOLUTION STANDARDS (e)

Sample No.	Radium Content (in micrograms) as of 1947	Approximate Weight	Price per Sample
4955	0.1	5 g	$32.00
4956	0.2	5 g	32.00
4957	0.5	5 g	32.00
4958	1.0	5 g	32.00
4959	2.0	5 g	32.00
4960	5.0	5 g	32.00
4961	10	5 g	32.00
4962	20	5 g	32.00
4963	50	5 g	32.00
4964	100	5 g	32.00

4990-A Contemporary Standard for Carbon-14-Dating Laboratories (sample consists of 1 lb of oxalic acid). No specific activity is given. These samples are shipped parcel post prepaid. $4.00

DISCONTINUED RADIOACTIVITY STANDARDS: The National Bureau of Standards has discontinued distribution of the following radioactivity standards: Radium D+E, cobalt-60, phosphorus-32, iodine-131, gold-198, strontium-yttrium-90, thallium-204, sodium-24, sulphur-35, zinc-65, cesium-137, potassium-42, tantalum-182, iron-59 and calcium-45, numbered respectively 4910, 4911, 4912, 4913, 4914, 4915, 4916, 4917, 4918, 4919, 4920, 4923, 4928, 4930, 4931, 4933, 4934, 4936 and 4942. Sources of these radionuclides may now be obtained commercially.

The stocks of standard samples of niobium-95, strontium-85, and scandium-46, Nos. 4937, 4938, 4939, respectively, have been depleted. Due to the relatively short half-lives of these radionuclides, and the low demand for standard samples of them, it is not economical to maintain a stock. No date has been set for the next distribution, but inquiries will be filed for notification of such. Meanwhile, chemically stable solutions of these and other radionuclides, can be submitted to NBS for calibration as described in the accompanying listing of calibration services: --

NOTE -- REQUESTS FOR THESE TESTS SHOULD BE SUBMITTED, WITH FULL DETAILS, FOR APPROVAL OF SUITABILITY.

Table 3d

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

November, 1964

CALIBRATION SERVICES

REQUESTS FOR TESTS SHOULD BE SUBMITTED, WITH FULL DETAILS, FOR APPROVAL.

204.201 Calibration of gamma-emitting radioactive samples

Calibration of gamma-emitting radioactive samples that conform to the physical, chemical, and activity level specifications for measurement in the National Bureau of Standards calibrated $4\pi\gamma$-ionization chamber.

Item	Description	Fee
204.201a	(1) 100-300 micrograms radium, calibrated in terms of micrograms of radium content measured relative to the National Radium Standard	$63.00
	(2) Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured	63.00
	i. 50-100 microcuries sodium-22, sodium-24, scandium-46, cobalt-60, yttrium-88.	
	ii. 150-300 microcuries manganese-54, iron-59, zinc-65, strontium-85, niobium-95, iodine-131, cesium-137, tantalum-182, gold-198, mercury-203.	
	iii. 300-600 microcuries potassium-42, cobalt-57.	
	Solutions should be 5 ml in volume and flame-sealed in glass vials or ampoules of O.D. 16.0 ± 0.5 mm, wall thickness approximately 0.5 mm.	
204.201b	Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured	80.00
	i. 10-20 microcuries sodium-22, sodium-24, scandium-46, cobalt-60, yttrium-88.	
	ii. 30-60 microcuries manganese-54, iron-59, zinc-65, strontium-85, niobium-95, iodine-131, cesium-137, tantalum-182, gold-198, mercury-203.	
	iii. 60-100 microcuries potassium-42, cobalt-57.	
	Solutions should be 5 ml in volume and flame-sealed in glass vials or ampoules of O.D. 16.0 ± 0.5 mm, wall thickness approximately 0.5 mm.	
204.201z	For tests not covered by the above schedule, fees will be charged dependent on the time involved in making the tests.	

Table 3e

204.202 Calibration of alpha-emission rate of sources

Calibration of alpha-emitting radioactive samples that conform to the physical and activity level specifications for measurement in the National Bureau of Standards $2\pi\alpha$-proportional counter.

Item	Description	Fee
204.202a	Chemically stable samples that conform to the physical and activity level specifications listed below can be measured	$51.00
	i. Source diameter should not exceed 10 cm.	
	ii. Source thickness should be such that more than 99.5% of the emitted alpha particles have an energy greater than 400 kev.	
	iii. Emission rate should not exceed 5×10^3 αps.	
204.202z	For tests not covered by the above schedule, fees will be charged dependent on time involved in making the tests.	

204.203 Calibration of beta-emitting radioactive samples

Calibration of beta-emitting radioactive samples that conform to the physical, chemical, and activity level specifications for measurement in either the National Bureau of Standards calibrated $2\pi\beta$-windowless proportional flow counter, or in the National Bureau of Standards calibrated $2\pi\beta$-ionization chamber.

Item	Description	Fee
204.203a	Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured in the National Bureau of Standards $2\pi\beta$-windowless proportional flow counter	$158.00
	i. 1-10 microcuries/milliliter chlorine-36, strontium-yttrium-90.	
	ii. 2-20 microcuries/milliliter thallium-204.	
	iii. 5-50 microcuries/milliliter calcium-45, promethium-147.	
	iv. 10-100 microcuries/milliliter sulfur-35.	
	Solutions should be approximately 5 ml in volume and flame-sealed in glass vials or ampoules.	
204.203b	Chemically stable solutions of the following radionuclides in the specified activity ranges can be measured in the National Bureau of Standards $2\pi\beta$-ionization chamber	90.00
	i. 2-20 microcuries/milliliter phosphorus-32. Solution should be neutral or weak acid with not more than 0.2 mg/ml total solids.	
	ii. 2-20 microcuries/milliliter strontium-yttrium-90. Solution should be weak HCl(1N or less) with not more than 0.2 mg/ml total solids.	
	Solutions should be approximately 5 ml in volume and flame-sealed in glass vials or ampoules.	
204.203z	For tests not covered by the above schedule, fees will be charged dependent on the time involved in making the tests.	

Table 4a

Radiological Equipment—Gamma-Ray Sources

204.501 X-ray and gamma-ray instruments

NOTE: Calibration of radiation beam within ± 2 percent.

Item	Description	Fee
204.501a	Calibration of one X-ray exposure-indicating instrument of one range, in international roentgens for lightly or moderately filtered X-rays of one half-value layer from the following selections	$48.00

Lightly filtered X-rays

Technique	kvcp	Approx. inherent filter	Added filter	Distance	Approx. first half-value layer	Homogeneity coefficient (1st HVL/2d HVL)	Instrument range from zero		Exposure rate	
							min.	max.	min.	max.
		mm Be	*mm* Al	*cm*	*mm* Al		*R*	*R*	*R/min*	*R/min*
LFD	20	0.25	0	50	0.06	0.42	100	500	50	200
LFD	20	.25	0	70	.07	----	50	100	20	80
LFD	20	.25	0	100	.08	----	25	50	7	30
LFE	20	.25	0.5	50	.20	.68	10	100	2	8
LFG	30	.25	.5	50	.33	.67	25	250	5	20
LFI	50	.25	1.0	50	.90	.68	25	250	6	25
LFK	75	.25	1.5	50	1.6	.66	25	250	10	22
LFM	100	.25	2.0	50	2.5	.63	25	250	14	25

Moderately filtered X-rays

Technique	kvcp	Approx. inherent filter	Added filter		Approx. first half-value layer		Homogeneity coefficient (1st HVL/2d HVL)	Instrument range from zero		Exposure rate	
			Cu	Al	Cu	Al		min.	max.	min.	max.
		mm Al	*mm*	*mm*	*mm*	*mm*		*R*	*R*	*R/min*	*R/min*
MFB	60	1.5	0	0	----	1.64	0.67	5	100	0.4	3.0
MFC	60	1.5	0	2.5	0.09	2.79	.77	5	100	.4	2.5
MFE	75	1.5	0	2.5	.11	3.41	.73	5	100	.4	4.0
MFG	100	1.5	0	3.5	.20	5.05	.73	5	100	.9	6.0
MFI	150	1.5	.25	3.5	.66	10.1	.87	5	100	1.0	8.0
MFK	200	1.5	.5	3.5	1.26	13.2	.92	10	250	2.0	13.0
MFM	250	1.5	1.0	3.5	2.17	16.2	.94	10	250	2.5	17.0
MFO	250	1.5	3.2	3.5	3.20	18.4	.98	10	250	1.3	10.0

Item	Description	Fee
204.501b	Calibration of each additional X-ray exposure-indicating instrument of the same range and for the same half-value layer of lightly or moderately filtered X-rays as selected under 204.501a and not requiring a change in setup and when the instruments are submitted at the same time	$18.00
204.501c	Calibration of one X-ray instrument, either exposure- or exposure-rate-indicating, in international roentgens for heavily filtered X-rays of one effective energy from the following selections	60.00

Table 4a (Cont'd)

*Heavily filtered X-rays**

Technique	kvcp	Approx. inherent filter	Added filter				Approximate			Instrument range from zero		Exposure rate	
			Pb	Sn	Cu	Al	Effective energy	HVL	HVL	min.	max.	min.	max.
		mm Al	*mm*	*mm*	*mm*	*mm*	*kev*	*mm* Cu	*mm* Al	*R*	*R*	*R/min*	*R/min*
HFC	50	1.5	.12	0	0	2.5	40	0.16	4.4	0.1	1	0.02	0.09
HFE	100	1.5	.53	0	0	2.5	70	.72	11.2	.1	5	.05	.27
HFG	150	1.5	0	1.5	4.0	2.5	120	2.4	16.8	.1	5	.04	.22
HFI	200	1.5	.7	4.0	0.6	2.5	170	4.1	19.5	.1	5	.03	.21
HFK	250	1.5	2.7	1.0	.6	2.5	215	5.4	21.5	.1	5	.03	.21

* Available on special arrangement.

Item	Description	Fee
204.501d	Calibration of each additional X-ray instrument of the same exposure or exposure-rate range, for heavily filtered X-rays of one effective energy as selected under 204.501c, not requiring a change in setup and when the instruments are submitted at the same time	$24.00
204.501e	Calibration of one instrument: (1) Exposure-rate-indicating instrument for exposure rates ranging from 0.01 to 15 R/min; or (2) Exposure-indicating instrument of range 0 to 0.1 R to 0 to 25 R, in international roentgens for cobalt 60 or cesium 137 gamma-rays	$42.00
204.501f	Calibration of each additional instrument having the same exposure or exposure-rate range for cobalt 60 or cesium 137 gamma-rays, as under 204.501e, when the instruments are submitted at the same time	17.00
204.501z	Calibration of one X-ray or gamma-ray instrument, exposure- or exposure-rate-indicating, in international roentgens: (1) Calibration of higher accuracy than that routinely furnished; or (2) Calibrations on X-rays of energies other than those listed under 204.501a, c, or e; or (3) Calibrations requiring a special setup or special procedures. Fees will be charged dependent upon the nature of the test. **Only a limited number of special calibrations can be undertaken and requests for such should be submitted with full details for consideration.**	

Table 4b

204.502 **Gamma-ray sources.** Radioactive preparations submitted to the Bureau for test are subject to the following conditions:

(a) Financial responsibility: The Bureau assumes no responsibility for loss or damage to radioactive preparations while in its possession. The risk should be covered by insurance.

(b) Period of measurement: Approximately 10 days are required for measurement of these radioactive preparations.

(c) Preparation of specimens: Radioactive preparations submitted for test must be carefully sealed so that there can be no escape of any radioactive material, including any gaseous decay products. The preparations, shielding, and packaging must be free of contamination. Contaminated or leaking preparations cannot be measured and may cause considerable loss of time and damage to laboratory facilities. Preparations must have been sealed for a sufficient time to be substantially in radioactive equilibrium with their decay products when these contribute to the gamma emission (at least 30 days for radium).

(d) Packaging for shipment: Regulations of the Interstate Commerce Commission regarding the shipment of radioactive substances by rail must be complied with. These regulations are enforceable by law and prospective shippers of these substances need to be familiar with them. Copies of the regulations can be obtained from the Interstate Commerce Commission, Washington, D.C., 20423.

(e) Possession of licensed material: In submitting specimens of cobalt 60 or other licensed source material (except radium, which is not licensed) for calibration, it will be necessary for the submitter to certify that he is duly authorized to possess the material under license by the USAEC, except in the case of individuals residing in a State which has entered into agreement with the USAEC, in which case State regulations are applicable. This certification may be by letter, by a suitable statement on the purchase order covering the calibration fee, or by a clear copy of the submitter's Possession License for the source material.

(f) Type of measurements:

(1) Radium is calibrated in terms of milligrams of equivalent radium content measured relative to the National Radium Standard through comparison of the gamma radiation from the specimen and the standard. Where the details of encapsulation of the specimen are known, corrections can be made to obtain milligrams of radium content. Cobalt 60 is calibrated in terms of exposure rate, milliroentgens per hour at one meter, based upon comparison with derived standards of cobalt 60.

(2) Postal regulations prohibit mailing radioactive materials which require a caution label under ICC regulations. This effectively prohibits placing radioactive preparations in the mail.

Item	Description	Fee
	Gamma-ray measurements of radioactive preparations; measurements of milligrams equivalent content to ±0.7 percent for radium; and milliroentgens per hour at one meter to ±3 percent for cobalt 60:	
204.502a	0.5 to 15 mg equivalent radium content or cobalt 60 having gamma-rays 0.5 to 15 mRhm (milliroentgens per hour at one meter)--------	$18.00
204.502b	15+ to 100 mg equivalent radium content or cobalt 60 having gamma-rays 15+ to 100 mRhm----------	28.00
204.502c	100+ to 250 mg equivalent radium content or cobalt 60 having gamma rays 100 to 200 mRhm----------	40.00
204.502d	For measurements in groups not exceeding 10 preparations, double the fee for preparations of same content as the total content of the group.	
204.502e	For handling and examination of a shipment containing contaminated or leaking preparations the fee will be the same as for measurements of a preparation having a content equal to the total nominal radioactive content of the shipment.	
204.502z	For special tests not covered by the above schedule, fees will be charged dependent upon the nature of the test. As only a limited number of special tests can be carried out, prior arrangements must be made including submission of full details concerning the required test.	

Table 5

Comparison of National Exposure Standards

Years	Other National Laboratory	Method	Percentage of Maximum Difference
1953	UK	direct	a/3.0
1956	UK	direct	0.5
1962	Canada	direct	0.3
1956	Sweden	indirect	0.8
1957	France	indirect	0.4
1963	Federal Rep/Germany		0.6
	France		0.4
	UK		b/ 1.0

a/ These measurements merely confirmed that the UK chamber was inadequate for the harder qualities.

b/ This comparison was within 0.5 percent of that obtained for the previous direct comparison.

U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20230

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